UNCLASSIFIED

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. N/A	3. RECIPIENT'S CATALOG NUMBER N/A
4. TITLE (and Subtitle) CONSTRUCTION OF A 345 GIGAHERTZ RECEIVER BASED ON SUPERCONDUCTING TUNNEL JUNCTIONS		5. TYPE OF REPORT & PERIOD COVERED Final Report 10/01/85 – 12/31/89
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Edmund C. Sutton		8. CONTRACT OR GRANT NUMBER(s) DAAG29-85-K-0254
9. PERFORMING ORGANIZATION NAME AND ADDRESS Space Sciences Laboratory University of California Berkeley, CA 94720		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office Post Office Box 12211 Research Triangle Park, NC 27709		12. REPORT DATE 02/12/90
		13. NUMBER OF PAGES 4
14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, If different from Report)

NA

18. SUPPLEMENTARY NOTES

The view, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

tunnel junctions
submillimeter
superconducting
mixer

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the construction of a 345 Gigahertz receiver system based on superconducting tunnel junctions. The junctions used are Niobium edge junctions, which are mounted in a waveguide mixer mount. Highest sensitivity occurs at 312 GHz with a measured receiver noise temperature of 275 K double sideband. Theoretical calculations and experimental results both indicate the likelihood of good low noise operation out to 1000 GHz using techniques of the sort described here.

Statement of the Problem Studied

Receiver performance at submillimeter wavelengths has for a long time lagged behind that exhibited at microwave and millimeter wavelengths. At the same time it has been clear that this is not indicative of any fundamental physical limitation and that in principle significantly more sensitive receiver systems could be designed. In this work we set out to investigate how improved performance could be achieved, through construction of a low-noise mixer-receiver for 345 GHz. This receiver was to be based on the mixing properties of superconducting tunnel junctions, which was expected to be the most promising approach. The project goal was to construct the most sensitive possible receiver system for this frequency and through this to also investigate the potential for future systems, particularly at yet higher frequencies.

Summary of Important Results

The important results from this work are discussed most fully in the four refereed publications which have resulted from this contract work. These publications are briefly discussed in the next four paragraphs. Following this is a section in which the main results are brought together and highlighted. Finally there is a brief separate discussion of progress during the final 6 month contract period (not included in any previous progress reports).

Danchi and Sutton (1986) discuss the frequency dependence of quasiparticle mixers. This paper is based on a set of theoretical calculations, in which noise properties and conversion efficiency have been predicted for mixing at frequencies up past 1000 GHz. This was important in providing a framework in which to evaluate our experimental results at 345 GHz. It was also important in enabling us to judge the potential for even higher frequency work. The calculations highlight the importance of two factors: subgap leakage and the superconducting energy gap. Subgap leakage affects both mixer noise and conversion efficiency. The energy gap $\Delta_1 + \Delta_2$ (for brevity, 2Δ) also affects both factors. The predicted performance deteriorates markedly at a frequency $\frac{2\Delta}{h}$ and again at $\frac{4\Delta}{h}$, so these effectively define an upper limit to the frequencies which can be reached. High frequency performance will depend strongly on the gap and therefore the materials employed. With current materials the upper limit is near 1200 GHz, although the use of other materials can extend this.

Danchi, Golightly, and Sutton (1989) discuss the inverse AC Josephson effect at terahertz frequencies. This work was also theoretical in nature. Although not directly related to the construction of our 345 GHz receiver system, it was an interesting effect which we encountered in the course of our calculational work. In essence it shows that due to the effect of the Reidel singularity it may be possible to observe Josephson steps at terahertz frequencies which cross the zero DC bias current axis, contrary to previous expectations. This has practical implications for the construction of voltage standards. The effects of the Reidel singularity also have relevance to the construction of high frequency mixers.

Danchi, Sutton, Jaminet, and Ono (1989) discuss the practical aspects of our junction fabrication process. We have employed Nb edge junctions with PbInAu counter electrodes. Cross sectional areas are approximately 0.1 μm^2 in order to yield the desired low capacitance (~ 30 fF) and satisfy the requirement for $\omega R_N C \approx 3$.

Sutton, Danchi, Jaminet, and Ono (1989) present a thorough discussion of our 345 GHz receiver, including details relating to design, fabrication, and testing. For optimum noise performance and good beam properties the mixer is contained in a waveguide mounting structure with a single tuning element (backshort) and a conical scalar feed horn. Tests gave best performance with junction impedances in the vicinity of 100 ohms. We have obtained our best sensitivity at 312 GHz where we measured a double sideband (DSB) noise temperature of 275 K and a conversion loss of 9.5 dB, in reasonable agreement with the predictions of Danchi and Sutton (1986). We have also obtained good sensitivity out through 360 GHz. In obtaining these results we have investigated two important additional effects. One is the effect of magnetic fields on mixer performance. We have found that modest magnetic fields can be used to suppress Josephson currents and the associated instabilities, with only minor effect on mixer performance. This will be important for future work at higher frequencies. Also we have demonstrated the ability to generate significant local oscillator power out to 500 GHz using an entirely solid state local oscillator system. With work this should be extendable out to 1000 GHz.

The above results can be summarized by the following three main points.

- Theoretical work indicates that low noise mixing with SIS tunnel junctions should be possible out to at least 1200 GHz. Performance at or beyond this limit will depend strongly on the choice of superconducting materials and the superconducting energy gap.

- It is possible to make a 345 GHz mixer with noise performance of 275 K (DSB).

- It is reasonable to expect that low noise tunnel junction receivers could be built out to 1000 GHz, with noise temperatures of less than 1000 K (DSB). Such systems would likely be able to employ solid state LO's.

The final six month contract period was not the subject of any previous progress report and therefore is summarized here. The instantaneous RF bandwidth of the receiver was studied by testing the degree of LO coupling at various frequencies and various backshort positions. Generally it was found that the RF bandwidth was of the order of 5 GHz, sufficient to couple both receiver sidebands as expected. With certain junctions with seemingly lower capacitances this bandwidth could be considerably larger. Tests both with and without applied magnetic fields showed the presence of only a minor amount of saturation. Our additional experience with magnetic fields has confirmed that this is a desirable mode of operation, with increased stability yet similar noise performance. We have also had an opportunity to test the system with a variety of junctions, confirming that the curve of noise temperature vs. frequency depends on junction impedance and also to a degree on junction position in the waveguide. Finally we have made some changes in our method of frequency control of the Gunn oscillator, which would simplify the design of higher frequency and higher power local oscillators.

List of Publications

Danchi, W.C. and Sutton, E.C. "Frequency Dependence of Quasiparticle Mixers," 1986, *J. Appl. Phys.* **60,** 3967.

Danchi, W.C., Golightly, W.J., and Sutton, E.C. "Inverse AC Josephson Effect at Terahertz Frequencies," 1989, *J. Appl. Phys.*, **65**, 2772.

Danchi, W.C., Sutton, E.C., Jaminet, P.A., and Ono, R.H. "Nb Edge Junction Process for Submillimeter Wave SIS Mixers," 1989, *IEEE Trans. Magn.*, **MAG-25**, 1064.

Sutton, E.C., Danchi, W.C., Jaminet, P.A., and Ono, R.H., "A Superconducting Tunnel Junction Receiver for 345 GHz," 1990, *Int. J. Infrared Millimeter Waves*, **11**, in press.

Scientific Personnel Supported by this Project

Dr. Edmund C. Sutton
Dr. William C. Danchi
Paul A. Jaminet
William J. Golightly (A.B. in Physics awarded June 1988)